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Research Article

Measuring shoulder abduction strength using 2 different dynamometers: comprehensive intrarater and interrater reliability and validity

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ABSTRACT

Objective: The purpose of this study is to investigate the intrarater and interrater reliability of handheld dynamometer (HHD) measurements in assessing isometric muscle strength of the shoulder abductors and to compare these results with those obtained using a fixed dynamometer (FD).

Methods: The study involved 25 voluntary participants, all over the age of 18, asymptomatic (with no injuries in the upper extremity), and not engaged in overhead sports. The participants were evaluated twice by 2 different testers who were experienced in orthopedic rehabilitation, at 90 degrees of shoulder abduction in the scapular plane. On the first measurement day, Tester 1 performed measurements using both HHD and FD, while on the second measurement day, both testers used only the HHD. A 3- to 7-day interval separated the 2 measurement sessions. Paired-samples *t*-tests were used to evaluate the systematic bias between the testers. Spearman's rank correlation coefficient, intraclass correlation coefficient, standard error of measurement, and minimal detectable change were calculated. The statistical significance level was accepted as $P < .05$.

Results: Data from 22 participants (15 women, 7 men; mean age: 23.00 ± 3.19 years) were analyzed, as 3 individuals did not attend the final assessment. A strong correlation (r=0.772) was found between Tester 1's HHD measurements and FD, while a similarly strong correlation (r=0.748) was observed for Tester 2's HHD measurements. Excellent intrarater reliability (intraclass correlation coefficient [ICC]=0.941) was found between Tester 1's measurements, and excellent interrater reliability (ICC=0.889) was found between testers.

Conclusion: Handheld dynamometer has demonstrated excellent interrater and intrarater reliability and high validity for assessing shoulder abductor muscle strength in research and clinical use. Since the muscle strength of testers using the HHD may influence the results, the FD may be a more appropriate option when the study population is stronger than the testers. Studies involving different clinical populations and testers with varying experience levels are needed to improve the relevance of the results.

Level of Evidence: Level III, Diagnostic Study.

Introduction

In rotator cuff (RC) pathologies, pain, shoulder movement impairment, and functional problems are commonly observed during shoulder elevation and external rotation.[1] Shoulder abduction in the scapular plane is considered the most functional abduction plane due to the optimal alignment of bones and muscles in the glenohumeral joint.[2] The deltoid and RC muscles play a significant role in shoulder abduction torque. The middle deltoid contributes 35%-65%, the subscapularis 30%, the supraspinatus 25%, and the infraspinatus 10%.[3] It has been observed that the supraspinatus tendon is most commonly affected among RC pathologies in studies using diagnostic imaging methods for shoulder pain.[4,5] The supraspinatus and the deltoid abduct the humerus and generate compression forces to stabilize the glenohumeral joint.[6,7] Researchers need accurate and reliable examination tools to objectively evaluate the functional status of the shoulder joint. Various physical examination methods have been defined to evaluate the RC, including special tests, strength measurements, and range of motion assessments.[8] Several methods are available for assessing shoulder abductor muscles, including manual muscle testing (MMT), handheld dynamometer (HHD), fixed dynamometer (FD), and isokinetic tests.[9-12] Clinicians often use MMT to assess strength. However, MMT is prone to false-negative results since it is a subjective assessment method. One study found that muscle groups with normal strength in MMT showed decreased strength when tested with a dynamometer.[13] Although isokinetic tests are considered the gold standard, they are not suitable for frequent use due to their high cost and the need for a laboratory setting.[11]Additionally, upper extremity muscles do not produce isokinetic muscle activity during daily functional tasks.[14]

The HHD is an easy-to-use device that is applied similarly to an MMT but provides a quantitative measurement of force. The advantages of HHD include its portability, low cost, ease of use, and minimal time requirement, making it a preferred tool for assessing shoulder muscle strength.[11,14,15,16] A review comparing the HHD with isokinetic tests has demonstrated that

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the HHD generally has moderate-to-good reliability and validity in assessing muscle strength.[11] However, the HHD also has some disadvantages. Its greatest limitation is the requirement for the clinician to provide adequate resistive force; otherwise, the contraction will not be isometric, and the measurement cannot be considered valid. The amount of resistive force that can be applied may vary depending on the tester's age, muscle strength, experience, and stabilization skills.[17] Another limiting factor is the variability among devices and measurement protocols, which negatively impacts consistency.[11,14,18] Recently, other devices, such as portable FD, have been developed, and the results have been promising.[19,20] The FD is also easy to use, portable, and cost-effective. Its main advantage is that the measurement does not depend on the testers' strength; therefore, the error rate can be reduced.[21] It is believed that HHD measurement may require external stabilization to eliminate the effect of the testers' strength and increase reliability.[22] In the FD evaluation, a dynamometer secured with a strap stabilizes the individual against a stationary object, and the person pulls isometrically.[23,24] Trajković et al[24] demonstrated good-to-excellent reliability in strength evaluation using FD in the shoulder, knee, and hip regions. A review of the current literature demonstrates that a variety of testing procedures and measurement devices are used to assess shoulder abduction muscle strength. [9-12,24] Furthermore, it is well established that measurements obtained using an HHD are influenced by examiner-related factors. According to a review examining the measurement properties of dynamometers used for shoulder muscle strength assessment, only 1 study comparing HHD and FD was identified. This study was conducted on a healthy population and provided low-quality evidence.[18] In clinical practice, it is not always possible to access isokinetic testing, which is considered the gold standard. Therefore, demonstrating the reliability and validity of alternative methods such as HHD and FD, which can be used in clinical settings, is valuable for researchers who intend to use these devices. In this context, the aim of the present study is to compare the reliability and outcomes of shoulder abduction strength measurements obtained using HHD and FD in a healthy population and to examine the relationship between examiner characteristics and the measurement results.

Material and methods

This study was conducted at the Physical Medicine and Rehabilitation Department of Koç University Hospital. Ethical approval was obtained from the Ethics Committee of Biruni University (Approval No.: 2022/73-01; Date: 08.18.2022) prior to the study. Written and oral consents were obtained from all participants. All procedures performed in the study were conducted in accordance with the 1964 Helsinki Declaration. The study included 25 participants (15 women and 10 men) over the age of 18 years. Individuals who had a shoulder injury within the last 6 months, a history of shoulder or neck surgery, neurological or systemic musculoskeletal problems, neck and shoulder symptoms during evaluation, or who had engaged in regular sports or exercise involving the upper extremity (due to potential muscle soreness and fatigue) in the past year were excluded from the study. Participants were instructed to avoid strenuous physical activities that could affect the upper extremity both prior to the test day and during the period between testing sessions. To reduce information bias, a minimum of 3 days were allowed between measurement sessions.

All tests were performed by a physiotherapist and a physiatrist who are experienced in orthopedic rehabilitation. Prior to the study, a pilot study involving 10 shoulder evaluations of participants with the same demographic characteristics was conducted. It was ensured that none of the participants had prior experience with HHD and FD.

The appropriate sample size for the study was calculated based on the study by Walter et al[25] With an intraclass correlation coefficient (ICC) of 0.70 (2 persons), α level of 0.05, and 80% power, at least 19 participants were required. The sample size was determined to be 25, considering the possibility of participant withdrawal from the study.[25]

Test procedure

Participants were informed that they should refrain from upper extremity strength training and avoid any overhead throwing activities during the study period to ensure the accuracy of the study. Standard 5-minute warm-up exercises were performed in all shoulder joint ranges of motion at the beginning of the test. On the first test day, participants participated in 2 strength tests to prevent fatigue. Tester 1 performed shoulder abductor muscle strength assessments using HHD and FD on the first test day. The second test day took place 3 to 7 days after the initial measurement, and both testers performed measurements using HHD. Thus, both intrarater reliability with Tester 1 and interrater reliability between the testers were assessed. The order of strength measurements (HHD or FD and Tester 1 or Tester 2) was randomized to avoid potential bias, and the test was conducted on the dominant arm. A 1-hour rest period was given between measurements and testers to prevent fatigue. The diagram illustrating the test procedure is presented in Figure 1. Isometric abduction strength was applied at 90 degrees of abduction, in a 30-degree scapular plane, with the elbow in full extension and the forearm in a neutral position (thumb up).[26] A 30-degree angle was marked on the floor with tape to align the participant's shoulder in the scapular plane. The participant's shoulder was placed in 90 degrees of abduction within the scapular plane using a goniometer. The HHD (Manual Muscle Tester, Lafayette) was placed 1 cm proximal to the radiocarpal joint (Figure 2). The participant was asked to exert maximum contraction against the dynamometer and hold it for 5 seconds. The testers instructed the participants to avoid body compensation during the test and provided standardized verbal encouragement ("Force! Force! Force!"). Measurements were recorded in Newtons. If the participant showed compensatory movements such as lifting the shoulder or bending the body, the test was stopped and repeated. The test was applied 3 times, and the average of them was calculated. A 30-second rest was given between repetitions to prevent fatigue.

An adjustable strap electronic FD (Mecmesin Myometer, West Sussex, UK) was used in the evaluation conducted with FD (Figure 3). During the test, the strap of the device, fixed to the table, was placed on the participant's wrist, and maximum voluntary isometric contraction was recorded simultaneously by a computer. All measurements were conducted by the testers using a standard protocol. Similarly, isometric abduction strength was applied at 90 degrees of abduction, within a 30-degree scapular plane, with the elbow in full extension and the forearm in a neutral position (thumb up). The participant's

HIGHLIGHTS

- The handheld dynamometer is a valid and reliable assessment tool for evaluating shoulder abduction muscle strength.
- There is a strong correlation between the handheld dynamometer and the fixed dynamometer in the evaluation of shoulder abduction muscle strength.
- The handheld dynamometer is a convenient tool for clinical use; however, it is influenced by the physical characteristics of the evaluator. Therefore, selecting an appropriate dynamometer for the assessed population is essential.

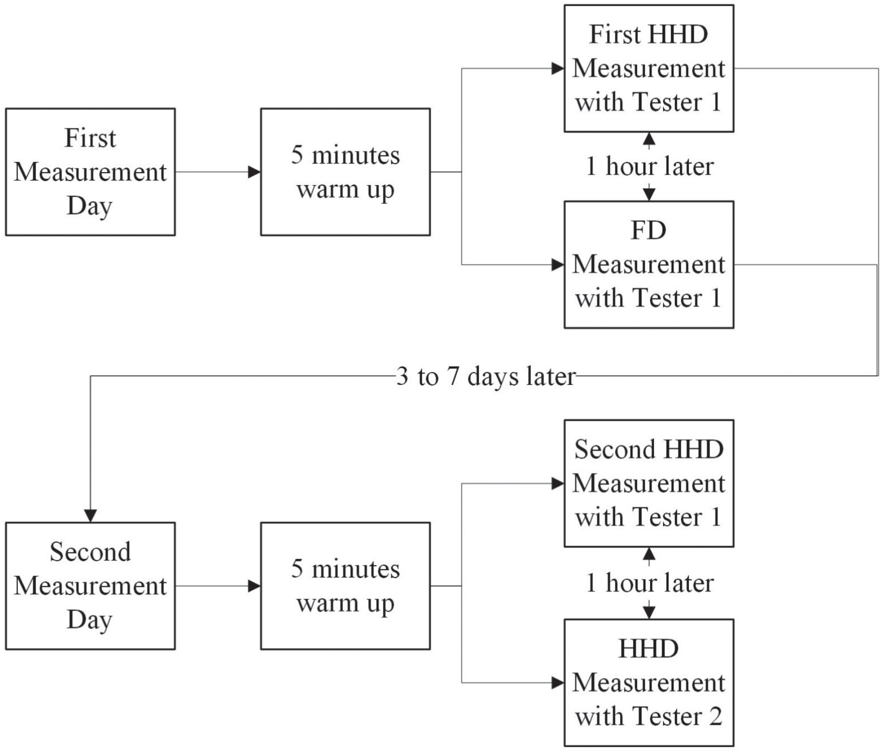

Figure 1. Diagram of the test procedure.

shoulder was positioned at 90 degrees of abduction within the scapular plane using a goniometer. For the tested shoulder, participants were instructed to push upward maximally 3 times consecutively for 5 seconds, with a 30-second interval between repetitions. The push and relaxation periods were monitored using a visual timer placed in front of the participants.[27] The testers asked the participants to

Figure 2. The testing position of the handheld dynamometer.

Figure 3. The testing position of the fixed dynamometer.

avoid any body compensations during the test, and standardized verbal encouragement was used ("Force! Force! Force!"). Measurements were recorded in Newtons. Participants were not informed about the results until all study procedures were completed, and the testers did not view the results during the measurements.

Data analysis

Variability around a mean value is presented as mean ± SD. Dependent variables were not normally distributed (Kolmogorov–Smirnov test), and therefore, non-parametric tests were applied. A one-sample *t*-test was conducted to assess whether the mean difference in measurements—either between different raters or between repeated measurements by the same rater—deviated from zero. The ICC (2,1) was calculated with corresponding 95% confidence intervals to determine intrarater and interrater reliability. Reliability was classified as excellent (ICC > 0.75), from moderate to good (ICC = 0.40-0.75), or poor (ICC < 0.40).[28] The standard error of measurement (SEM) was calculated as SD × √(1 - ICC), and minimal detectable change (MDC) was calculated as SEM × 1.96 × √2.[29] Since test scores varied between and within individuals, SEM% was calculated by dividing the SEM by the average of the retest values to make a more meaningful comparison. To determine concurrent validity, Spearman's rank correlation coefficients were calculated to assess the agreement between HHD and FD results. Correlations were considered strong (rho ≥ 0.70), moderate (rho = 0.40-0.69), and weak (rho < 0.40).[30] The statistical significance level was accepted as $P < .05$.

Results

Data from 22 participants (15 women, 7 men; mean age: 23.00 ± 3.19 years) were analyzed, as 3 of the 25 participants did not attend the final evaluation (Table 1). The correlation between FD and HHD measurements is shown in Table 2. A strong correlation was observed between FD and both Tester 1's second HHD measurement (r = 0.772) and Tester 2's HHD measurement (r = 0.748). The correlation and ICC between the HHD measurements conducted by the testers are presented in Table 3. A strong correlation (r = 0.870) was found between Tester 1's first and second HHD measurements, and an ICC of 0.941 was obtained. A strong correlation (r = 0.868) was found between Tester 1's second HHD measurement and Tester 2's HHD measurement, and an ICC of 0.889 was obtained.

Table 1. Demographic characteristics of the participants

Variables		Statistic
Sex (n%)	Woman	15 (68.2)
	Man	7 (31.8)
Dominant hand (n%)	Right	21 (95.5)
	Left	1 (4.5)
Age (year)		23.00 ± 3.19
BMI (kg/m²)		23.70 ± 3.91

BMI, body mass index.

Table 2. Validity results of shoulder abduction measurement

FD	Mean ± SD	Median (min-max)	Spearman's rank correlation coefficients	P
HHD2	74.11 ± 28.69	65.45 (45.80-147.57)	0.772	<.001
HHD3	80.81 ± 23.75	74.10 (46.67-136.83)	0.748	<.001

FD, fixed dynamometer; HHD2, Tester 1's second handheld dynamometer measurement; HHD3, Tester 2's handheld dynamometer measurement.

Discussion

In the evaluation of shoulder abduction strength, HHD demonstrated excellent intrarater and interrater reliability, as well as high validity. A strong correlation was observed between the FD measurement and Tester 1's and Tester 2's HHD measurements (r = 0.772, r = 0.748). A strong correlation was found within the intrarater HHD measurements (r = 0.870), as well as between interrater HHD measurements.

In the clinical examination of RC muscles, the evaluation of shoulder rotation and abduction strength (particularly of the supraspinatus) is included. As part of the superior RC, the supraspinatus contributes to external rotation and shoulder abduction and is the most frequently torn RC tendon.[31] There are limited data on the importance of strength measurement using a handheld dynamometer in diagnosing tears of the supraspinatus or other RC tendons.[32-34]Miller et al[35] investigated a group of individuals with shoulder pain and found decreased shoulder abduction and external rotation strength in those with supraspinatus tears identified through magnetic resonance imaging. In a study of 237 asymptomatic patients with RC tears, it was shown that individuals with large to massive full-thickness RC tears exhibited significantly reduced isometric muscle strength during abduction in the scapular plane.[33]In this study, by including the evaluation of shoulder abduction strength in asymptomatic individuals using HHD and FD, it was demonstrated that both dynamometers are valid and appropriate instruments for the assessment of shoulder abduction muscle strength.

Hayes et al[9] assessed isometric shoulder strength in participants with shoulder complaints, whose mean age ranged from 64 to 66, using 3 different measurement devices (MMT, HHD, and a spring scale dynamometer). They reported that HHD demonstrated excellent interrater reliability (ICC = 0.92) and intrarater reliability (ICC = 0.96) for shoulder elevation strength measurement. In this study, isometric abduction strength was evaluated and compared using both HHD and FD in a young, healthy population. Karabay et al[10]tested the eccentric strength of the shoulder abductor muscles using HHD, demonstrating excellent intrarater and interrater reliability and high validity compared to an isokinetic dynamometer. This study focused on the evaluation of isometric shoulder abduction muscle strength, with a comparative analysis conducted between HHD and FD. Similarly, these results also demonstrated excellent intrarater reliability (ICC = 0.941) and excellent interrater reliability (ICC = 0.889).

Vermeulen et al[12] used HHD (MicroFET2) and FD (Isobex2.1) in the evaluation of shoulder and elbow muscle strength in healthy participants and found that both dynamometers demonstrated similar intrarater and interrater reliability. Additionally, they reported that both

Table 3. Reliability results of shoulder abduction measurement

HHD2	Mean ± SD	Median (min-max)	Spearman's rank correlation coefficients	P	Intraclass correlation coefficient (95% CI)	SEM	SEM%	MDC
HHD1	73.97 ± 30.60	61.80 (35.80-142.03)	0.870	<.001	0.941 (0.863, 0.975)	7.43	10.05	20.59
HHD3	80.81 ± 23.75	74.10 (46.67-136.83)	0.868	<.001	0.889 (0.751, 0.952)	7.91	9.79	21.92

HHD1, Tester 1's first handheld dynamometer measurement; HHD2, Tester 1's second handheld dynamometer measurement; HHD3, Tester 2's handheld dynamometer measurement; MDC, minimal detectable change; SEM, standard error of measurement.

the dynamometers and the testers who used them influenced the measurements. In this study, shoulder abduction strength in healthy individuals was assessed using both HHD and FD. However, the measurement devices (HHD: Manual Muscle Tester, Lafayette, and FD: Mecmesin Myometer) and the test procedures were different. Despite the variations in equipment and the involvement of different researchers, the results of the evaluation demonstrated excellent reliability.

A strong correlation was also observed in this study between the FD measurement and the HHD measurements of both Tester 1 and Tester 2. Therefore, it is suggested that FD may be more suitable for assessing individuals with greater muscle strength, such as elite athletes. Beshay et al,[26] who evaluated shoulder muscle strength using both HHD and FD, found that FD did not provide a clinically significant advantage over HHD. However, FD was found to be more beneficial in assessing abduction muscle strength in the scapular plane among stronger participants. Previous studies have shown that the strength of the tester can lead to variations in measurement outcomes when using dynamometers.[36]Stronger testers could generate higher force outputs due to their greater resistance capabilities, while some testers could be weaker than the participants being tested. In the case of elite athletes, even when injured, they could possess greater strength than the tester, making stabilization more challenging for such patients. In such scenarios, clinicians aiming to assess isometric strength may benefit more from using an FD.[26,37]In this study, a physiotherapist and a physiatrist with experience in orthopedic rehabilitation were involved. A strong correlation was observed between the testers, indicating that the testers had appropriate strength levels for the participants in this study. Although not included in this study, in a shoulder abduction strength assessment involving elite athletes, the muscle strength or gender of the tester using HHD could have introduced a potential bias.

Standard error of measurement and MDC values are crucial in the clinical decision-making process, and smaller values indicate higher sensitivity.[29]standard error of measurement estimates how repeated measurements taken with the same instrument are distributed around the true score of an individual. In this study, the SEM for intrarater reliability was measured as 7.43, and for interrater reliability as 7.91. The SEM% values ranged from 9.79% to 10.05%, which are consistent with the SEM% values reported in studies assessing the eccentric muscle strength of the shoulder external rotators (6.8% - 9.2% - 12.0%).[38]

In this study, to minimize information bias, the testers were blinded to the participants' measured strength values. However, while the tester was unaware of the numerical value being measured, they were still aware of the resistance exerted by the participant, meaning that complete blinding cannot be claimed. Nevertheless, since the measurements were repeated on different days and the tester would not be able to recall the numerical value, it is believed that information bias was minimized. The primary limitation of this study is that it involved young, asymptomatic participants who are not overhead athletes, and the sample size was small. Additionally, not evaluating the study's applicability to symptomatic populations (e.g., patients with RC pathology) is another limitation. In tests performed with HHD, the strength of the tester should exceed the strength of the participant; otherwise, the test would be invalid. The testers in this study were able to successfully complete all the tests. However, testing elite athletes using the current HHD method could be challenging. Since the testers are likely to be stronger than patients with shoulder issues, such as RC syndrome, it is anticipated that measurements could be successfully conducted. Therefore, future studies could include a comparative evaluation of HHD and FD in both different clinical populations and elite athletes, and examine different tester-experience levels. Examining the effectiveness of objective strength assessment methods in individuals with RC pathologies would be particularly valuable. Nevertheless, the results of this study are considered important in providing normative values for healthy individuals. It is recommended that both clinicians and researchers use both HHD and FD when assessing individuals with shoulder complaints. However, in cases where the participant's muscle strength is known to exceed that of the tester—such as elite athletes—it is recommended to use FD for more accurate and reliable measurements.

In conclusion, HHD has demonstrated excellent interrater and intrarater reliability and high validity for the assessment of shoulder abductor muscle strength in both research and clinical use. A strong correlation has been shown between HHD and FD. The characteristics of the testers using HHD can influence the results; therefore, selecting a dynamometer suitable for the population being studied (shoulder pathologies, healthy individuals, or elite athletes) is important. When the tester is stronger than the population being assessed—such as in individuals with RC pathology—HHD is an appropriate and practical tool. However, in elite athletes, due to their greater muscle strength, FD is a more suitable option.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: This study was approved by Ethics Committee of Biruni University (Approval No.: 2022/73-01; Date: 08.18.2022).

Informed Consent: Written informed consent was obtained from the participants who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

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